

# European Wind Atlas and Wind Resource Research in Denmark

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# 風力エネルギー利用の現状と国際協力開発

# The Status of Wind Energy Generation and International Cooperative Activities

平成12年 6 月19日

主　催　　ユネスコ、国際連合大学
日本大学国際産業技術・ビジネス育成センター





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# プログラム（目 次）
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プログラムアソシエート）

# European Wind Atlas and Wind Resource Research in Denmark

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**Abstract**
The assessment of the available and exploitable resource base is naturally of primary concern to any power-producing technology. For wind power, this translates into assessment of the long-term wind speed and wind direction distributions at typical wind turbine hub heights – on a global, national, regional and local scale. In broad terms, *wind resource assessment* covers this entire range: from assessing the wind resource on a global scale to estimating the power production of a specific wind turbine at a specific site.

Many different tools and techniques have been used for wind resource assessment – from wind measurements at prospective sites to wind tunnel simulations and advanced flow modelling. Among these approaches, the *wind atlas methodology* – developed at Risø National Laboratory over the last 25 years – has gained widespread recognition and is presently considered by many as the industry-standard tool for wind resource assessment and siting of wind turbines. The PC-implementation of the methodology, the Wind Atlas Analysis and Application Program (WAsP), has been applied in more than 70 countries and territories world-wide.

The wind atlas methodology is based on physical descriptions and models of the wind flow, i.e. how the wind is transformed by the characteristics of the terrain over which is blows. The *analysis* part of the procedure estimates the influence of the topography surrounding a meteorological station and transforms the observed wind climate at this particular point into a regional wind climate which is valid for a region around the station. Several met. station analyses can be compiled into a *wind atlas*, which is then a description of the wind potential of a much larger area, say, a country or territory. The *application* part of the procedure employs the same models in reverse, in order to estimate the actual wind climate at any specific site and height within this region.

The Danish and European Wind Atlases are examples of how the wind atlas methodology can be employed to estimate the wind resource potential for a country or a sub-continent. Recently, the methodology has also been used to determine and map the actual, expected wind resource of Denmark (an area of about 43,000 $km^2$) with a high spatial resolution. Most applications of WAsP however, are concerned with estimating the expected power production from single wind turbines and wind farms. Examples from different parts of the world illustrate this and also serve to highlight the merits and limitations of the wind atlas methodology. Ongoing work at Risø to overcome these limitations will also be presented.

## European Wind Atlas and Wind Resource Research in Denmark

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UNESCO/UNU/Nubic Joint Seminar on
Global Wind Energy Utilization
June 2000, Tokyo, Japan

## Introduction and outline

- **Wind Resource Research**
  - focus here on wind resource assessment and siting
  - for information about other activities, please visit www.risoe.dk/vea or www.windpower.dk
- **... in Denmark**
  - at Risø National Laboratory, where > 100 persons work with wind energy-related activities and projects
- **European Wind Atlas**
  - a significant mile-stone, but far from the only interesting result of > 25 years of research
- **The historical perspective**
  - significant mile-stones over the last couple of decades
- **... and a look to the future**

## Wind Energy Research at Risø

- **The 1950's: Risø is founded in 1956**
  - Observations at the Risø met. tower
- **The 1960's: Laying the foundation**
  - Micro-meteorology and Climate (1969)
- **The 1970's: The early years**
  - Wind Atlas for Denmark (1979)
- **The 1980's: The long haul...**
  - European Wind Atlas (1989)
- **The 1990's: New opportunities**
  - Wind Resource Atlas for Denmark (1999)
- **The future: One world, one atlas?**
  - Wind Atlas for the World (2009?)

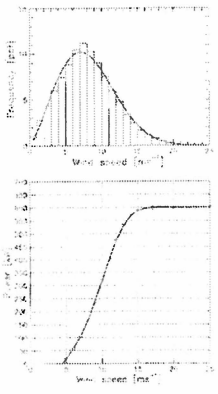
## The 1960's: Laying the foundation

- **Boundary layer meteorology**
  - surface layer meteorology
  - turbulence studies
  - climatology
- **Experimental meteorology**
  - surface layer experiments
  - long-term meteorological monitoring
  - instrument design and development
- **Applied meteorology**
  - air pollution and dispersion
  - pre-investigations for nuclear power plants
  - wind loads and wind engineering

## The 1970's: The early years

- **The basic problem**
  - prediction of actual wind resource at specific sites
  - inter- and extrapolation of wind climate statistics
- **The Wind Atlas Methodology**
  - from geostrophic wind climate to local wind climate
  - procedures to handle roughness and sheltering obstacles
  - guidelines and simple rules for hills and escarpments
- **Danish Wind Atlas**
  - 13 years of observations at 55 pressure stations
  - one geostrophic (regional) wind climate statistic + wind rose
  - tables, graphs and a User's Guide
  - most important tool: the pocket calculator

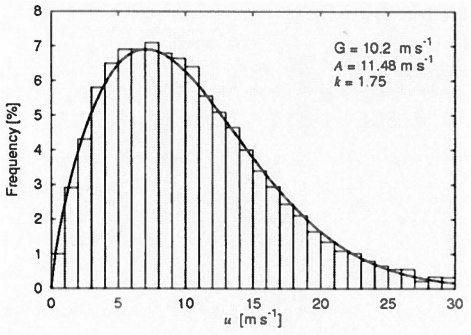
## Power production basics



- **Wind speed distribution**
  - total wind speed distribution
  - wind direction distribution (rose)
  - sector-wise wind speed distrbutions
  - represented be Weibull parameters
- **Wind turbine power curve**
  - production as function of wind speed
  - cut-in and cut-out speeds
  - rated power
- **Annual Energy Production (AEP)**
  - production integrated to 1 mean year

## The basic problem

## Danish Wind Atlas

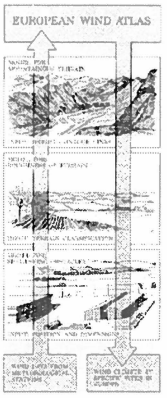



## The 1980's: The long haul...

- **Double-vertical extrapolation method**
  - further development of the wind atlas methodology; using mainly surface observations of wind speed and direction
  - Analysis: from met. station to regional wind climate
  - Application: from regional wind climate to wind turbine site
- **Wind Atlas Analysis and Application Program (WAsP)**
  - PC implementation of the wind atlas methodology
  - numerical models for obstacles, roughness and orography
  - advanced flow modelling on a desktop PC
  - versions 1 and 2 for DOS (no graphics)
- **European Wind Atlas**

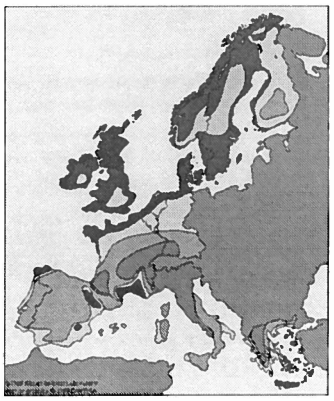
## Wind atlas methodology

- **Wind data analysis**
  - from time-series to Weibull parameters
- **Analysis of Observed Wind Climate**
  - model for sheltering obstacles
  - model for roughness/roughness change
  - model for flow over hills and orography
- **Regional Wind Climate estimation**
  - a wind atlas is a collection of RWC's
- **Application of wind atlas data sets**
  - same models applied in reverse
- **Prediction of site-specific wind climate**
  - Weibull *A*- and *k*-parameters + wind rose for specific site and height a.g.l.




## European Wind Atlas

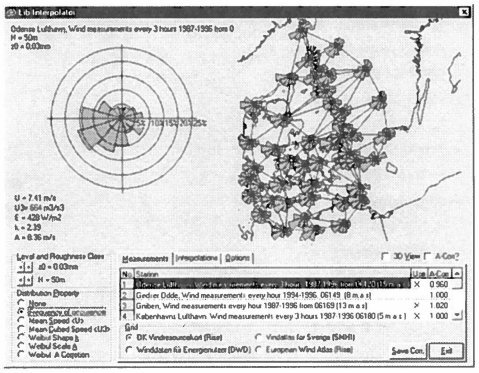
- **12 countries in the EC**
- **220 met. stations (10y)**
  - wind data analysis
  - wind atlas analysis
- **656 page book**
  - EC wind potential
  - siting handbook
  - database
- **1 data diskette**
  - observed data
  - modelled data
- **8 years of work!**
  - > 15 man-years



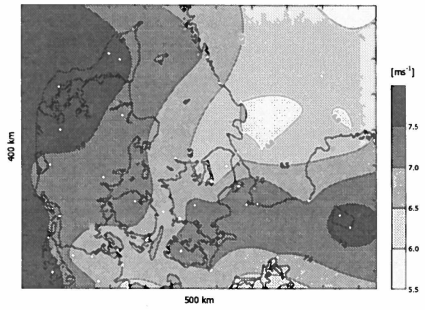
## The 1990's: New opportunities

- **WAsP program developments**
  - versions 3, 4 and 5 for DOS (16/32-bit + graphics)
  - versions 6 and 7 for Windows + Utility Programs
- **Wind Resource Atlas for Denmark**
  - methodology for wind resource mapping
- **Combination of micro- and meso-scale models**
  - the WAsP/KAMM methodology
- **Combination of micro- and operational NWP-models**
  - the short-term prediction model
- **International consulting services**
  - Cape Verde, Egypt, Europe, India, Jordan, Korea, Lesotho, Libya, Mexico, Mongolia, Nepal, P.R. China, Russia, Somalia, South Africa, Syria, Tanzania, ...

## WAsP analysis and interpolation



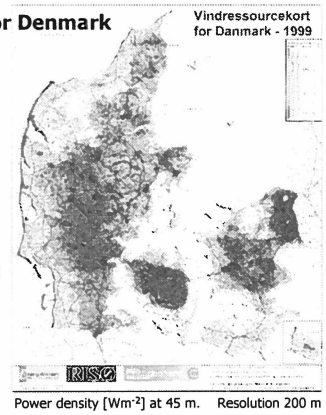
## Regional wind climate of Denmark




Mean wind speed [ms$^{-1}$] at 50 m over $z_0$ = 0.03 m

## Wind Resource Atlas for Denmark

- **Land area of 43,000 km²**
- **Topographical inputs**
  - terrain elevations (5-m)
  - 6 classes of land use
  - terrain roughness map
- **WAsP modelling**
  - regional wind climate
  - *P*-correction factors
  - regular grid (Δ = 200 m)
- **Database of resources**
  - Wind roses for all points
  - Weibull *A, k* and power density for four heights: 25, 45, 70 and 100 m

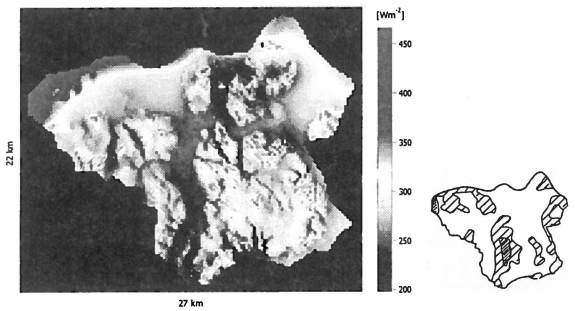



Power density [Wm$^{-2}$] at 45 m. Resolution 200 m

## 16Verification of predictions

- **1200+ wind turbines selected**
  - availability/quality of prod. data
  - minimum rated power 75 kW
  - doc. history and performance
  - power curves checked extensively
- **Actual and predicted productions**
  - > 80% predicted to within ±10%
  - about 10% of predictions > 110%
  - about 10% of predictions < 90%
  - about 25 WT's: difference > 20%
  - large differences due to shelter effects or input data errors


## Map of mean power density of Aalborg




Resource Atlas 1999 (Δ = 200 m)

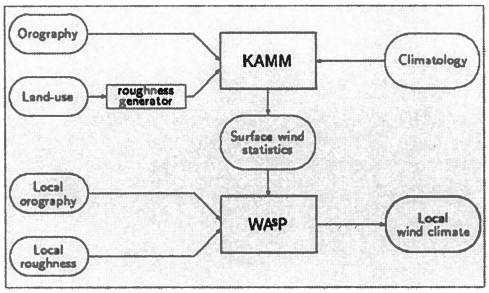


1992 DEA version...

## Combination of micro- and meso-scale models

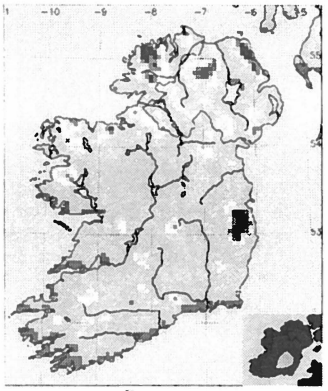
- **Limitations of the wind atlas methodology (WAsP)**
  - Prevailing conditions must be near-neutral
  - Meso-scale effects not taken into account
  - Orography must be gentle (attached flow)
- **One solution: hierarchy af models**
  - Global NCEP/NCAR re-analysis data or met. data as input
  - Meso-scale model (KAMM) Δ ~ 5 km
  - Micro-scale model (WAsP) Δ ~ 0.01 km
- **KAMM/WAsP modelling in Ireland**
  - Karlsruhe Atmospheric Meso-scale Model
  - The KAMM/WAsP methodology
  - Modelling results for Ireland
  - Comparison of KAMM/WAsP and measurements

## The KAMM/WAsP methodology




## Wind atlas for Ireland

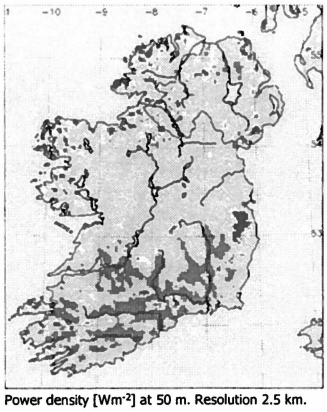
- **Wind atlas data, Δ=5km**
  - wind speed distributions
  - wind direction roses
- **Standard conditions**
  - 12 sectors
  - 5 heights a.g.l.
  - 4 roughess classes
- **Improvements**
  - meso-scale effects
  - stability effects
  - high resolution
  - coherent & continuous
  - digital wind atlas



Power density [$Wm^{-2}$] at 50 m. Resolution 5 km.

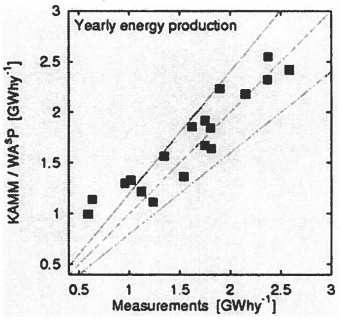
## Wind resource map

- **Wind climate and wind power predictions**
  - local roughness used
  - high resolution (2.5 km)
  - about 100 h CPU time
  - national and regional planning & prospecting
- **Limitations**
  - data limitations
  - model limitations
  - resolution too low for detailed wind farm and wind turbine calculation



Power density [$Wm^{-2}$] at 50 m. Resolution 2.5 km.

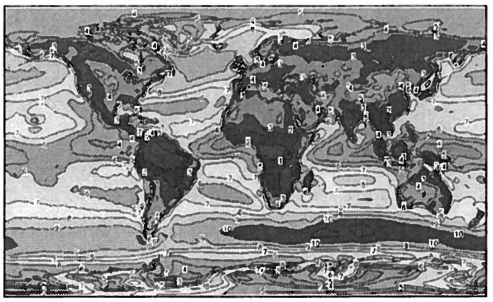
## Comparison of KAMM/WAsP and measurements




## The future: One world, one atlas?

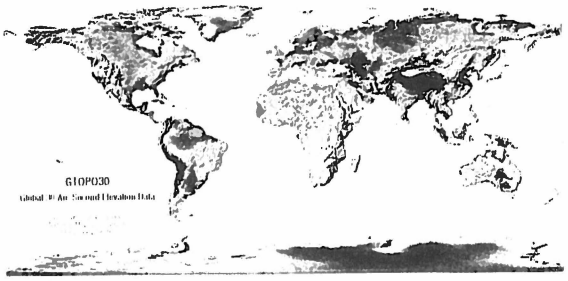
- **Hardware developments**
  - bigger (GB) and faster (GHz) computers
- **Software developments**
  - more advanced and complete physical models
  - modelling hierarchy (global-, meso- and micro-scale)
  - new models: WAsP Engineering (turbulence, extremes, gust)
- **Data developments/global databases**
  - climatological data from the re-analysis projects
  - elevation data with ~ 30-m horizontal resolution
  - reliable land use data with high resolution
  - novel digital maps with much more detailed info
- **Wind Atlas for the World**
  - verification against existing data

## NCEP/NCAR global climatological data



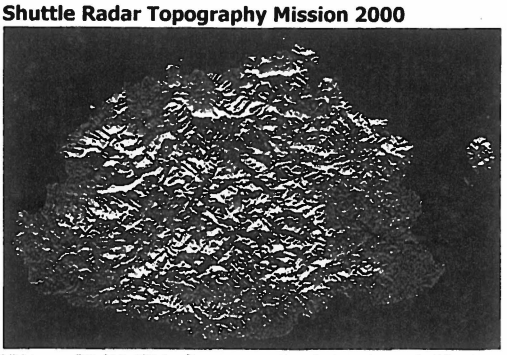
Mean wind speed [$ms^{-1}$] Resolution: 2.5 deg. (~250 km)

## GTOPO30 global elevation data




Grid-point elevations Resolution: 30 sec. (~900 m)

## Shuttle Radar Topography Mission 2000

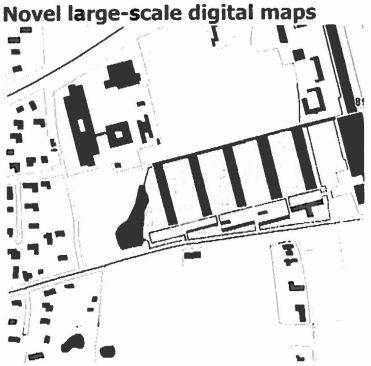


Viti Levu, Fiji (10,429 km²) Resolution: 1 sec. (~30 m)

## GLCC global land cover data

Eurasia Resolution: 1 km

## Novel large-scale digital maps



Accuracy: < 1 m Resolution: <1 m

## Wind atlases of the world for verification

**Red:** national wind atlas **Blue:** regional and/or local studies

## Concluding remarks

- **Wind power utilization scales**
  - local (wind turbine and wind farm)
  - regional (wind resource maps for planning)
  - national (wind resource maps for prospecting)
  - global (wind resource maps for resource assessment)
- **Industry-grade tools and models exist already, but...**
- **Wishes for the (near) future**
  - more reliable, long-term wind and other data
  - improved models for complex and mountainous terrain
  - improved models for turbulence and extreme winds
  - improved models for wake effects and wind loads
  - improved models for short-term prediction
  - improved understanding of offshore conditions